Winter Flounder Abundance Near Brayton Point Station, Mt. Hope Bay Revisited: Separating Local from Regional Impacts using Long Term Abundance Data.

By

Mark Gibson
RI Division of Fish and Wildlife
Marine Fisheries
4808 Tower Hill Rd
Wakefield, RI 02879
March 2002

RI Division of Fish and Wildlife
Research Reference Document 02/1

Winter Flounder Abundance Near Brayton Point Station, Mt. Hope Bay Revisited: Separating Local from Regional Impacts using Long Term Abundance Data.

By

Mark Gibson
RI Division of Fish and Wildlife
Marine Fisheries
4808 Tower Hill Rd
Wakefield, RI 02879

March 2002

Introduction-

Power generation at Brayton Point Station (BPS) on Mt. Hope Bay has been implicated in the collapse of winter flounder in Mt. Hope Bay (Gibson 1994, 1996). As a result, the permitting process for the facility is focused on conditions that will allow for recovery of the fish population to a balanced and indigenous status by meeting state water quality standards. The company that owns the facility, USGEN of New England, does not accept that impacts from the plant have contributed to the decline of fish in the area. In their partial 316(a) and 316(b) variance request application, the company argues that over fishing is the primary determinant of winter flounder abundance and that the failure to recover in Mt. Hope Bay is a result of continued over fishing (USGEN 2001). The company uses an age structured population model based on the Leslie matrix with density dependent elements, to project the trajectory of the Mt. Hope Bay winter flounder stock. An obvious problem is the lack of concordance between model estimates and observed data in recent years. Specifically, the model projects an increase in winter flounder abundance in response to reduced fishing mortality whereas the observed trawl and impingement data indicate no increase. The evidence for a reduction in fishing mortality rate in recent years is strong (Gibson 2000 and updates) suggesting that other factors are responsible for the continued low abundance near Brayton Point Station.

The Gibson (1996) report compared trawl survey abundance trends for a number of species including winter flounder and showed that the trends in Mt. Hope Bay near the station were anomalous with respect to the region. He concluded that adverse impacts from entrainment and waste heat rejection were the most likely cause. The methods used included an ARIMA time series model with an intervention term centered on 1985-1986. This period coincides with the conversion of unit 4 from closed to open cycle cooling. The results showed that a significant and negative intervention term was present in Mt. Hope Bay data but not for other nearby areas. In this report, winter flounder abundance trends are further analyzed to examine impacts from the facility and to gain incite on permit conditions, which might lead to stock recovery. The Rhode Island Department of Environmental Management (RIDEM) has maintained from the onset of the process that plant operational conditions prior to 1985 are a logical starting point, but not necessarily an end result, for future permit conditions. BPS has been in commercial operation since April of 1963 so that impacts to local fishery resources may have begun well before unit 4 modifications.

Methods and Data Sources-

BACI Approach- The preferred method to assess environmental impacts from industrial activity such as power generation is the before-after-control-impact (BACI) sample design using analytical procedures that account for serial correlation in the observed data (Madenjian et al. 1986, Manley 2001). The Gibson (1996) analysis was consistent with BACI design in that abundance series in the vicinity of the station and away from the station were examined before and after the 1985-1986 modification of unit 4. Time series methods that explicitly accounted for serial correlation were used. That analysis however dealt with the issue of additional impacts from unit 4. Brayton Point Station has four generating units, the first three of which went on line from 1963 to 1969. Total generating capacity of the four units is 1150 megawatts. Fish monitoring data for Mt. Hope Bay are not available prior to 1972. Although unit 4 modifications likely played a decisive role in the abrupt collapse of winter flounder, the population may have been impacted earlier, particularly with the addition of the 650 MW unit 3 in July of 1969. Lack of monitoring data prior to 1972 prevents full utilization of the BACI approach to estimate impacts prior to unit 4 modifications. However, the control-impact design (CI) post event may be used provided that care is exercised in selecting the control areas (Manley 2001).

Relative Abundance Data- Four trawl surveys were used as the primary measure of winter flounder abundance in the Rhode Island area. Data from Marine Research Inc. (MRI) trawling in Mt. Hope Bay and from Rhode Island Division of Fish and Wildlife (RIDFW) and University of Rhode Island Graduate School of Oceanography (URIGSO) studies in Narragansett Bay and adjacent Block Island and Rhode Island Sounds were examined from 1972 to 2000. I also used the National Marine Fisheries Service (NMFS) trawl survey conducted in the federal waters of the sounds. Details of the survey designs and methodology may be found in USGENMRI (1999), Lynch (1999), Jeffries et al. (1989), Grosslein (1969) and Clark (1979). Briefly, MRI conducts monthly trawling at 6 fixed stations in Mt. Hope Bay. Five stations are in the upper portion near BPS and one is located mid-bay near Spar Island. From 1969 to 1978, the RIDFW survey utilized a fixed station design with different trawl gear. Gibson (1987), computed abundance indices with adjustments for area swept to be comparable with the modern survey. Since 1979, the RIDFW has conducted spring and fall cruises in Narragansett Bay and nearby coastal waters with a random stratified design and 42 tows per cruise. Stratification is by depth. Annually, between 3% and 10% of the RIDFW seasonal tows have fallen in the Rhode Island waters of Mt. Hope Bay. RIDFW trawling in Mt. Hope Bay is limited to strata south of Spar Island and does not overlap the MRI survey. The URIGSO trawl survey is conducted at two fixed stations in the lower west passage of Narragansett Bay on a weekly basis. J. Collie, URIGSO- pers. comm, provided recent data for the survey, which dates back to 1959. The NMFS survey is of random stratified design. Seasonal (spring and fall) cruises are made with stations allocated to inshore strata.

I also examined commercial landings in the RI area as a gross measure of winter flounder abundance. Landings from NMFS statistical area 539, which includes Narragansett Bay and RI coastal waters, were obtained. Winter flounder have been significantly exploited in the New England area since the early 1900's (Perlmutter 1947). Consequently, large fluctuations in commercial landings are more likely related to changes in abundance than to effort. For example, from 1975 to 1985 commercial landings in area 539 tripled while Anthony (1990) reported less than a doubling of standardized fishing effort. Further, commercial landings are significantly correlated ($P<0.01$) with the RIDFW, URIGSO and NMFS long-term trawl surveys.

The Company identified impingement data at BPS as a more robust measure of abundance than trawl surveys in their 316(a) (b) partial demonstration (USGEN 2001). Although impingement indices have been demonstrated to be of limited value in detecting abundance changes (Van Winkle et al. 1981) and trawl survey data has been shown superior over fishery dependent data (Harley et al. 2001), I considered their impingement data in this study. Specifically, the MRI standardized impingement series for Mt. Hope Bay was considered as an alternate impact series and the MRI impingement data from the Providence River near Manchester Street Station (MSS) was considered as an alternate control series.

<u>Statistical Procedures</u>- The CI design relies on an assumption that the control abundance series is broadly representative of the population in question and that the impact series contains additional information from a local influence. In this case, taking the ratio of corresponding series values produces a series indicative of the local impact as information common to both series is cancelled out. A test for trend in the adjusted series reveals the significance of the local impact. A control and impact abundance series that contain the same trend information will produce a ratio series without trend (Appendix). A significant trend in the ratio series indicates a local impact or an inappropriate control series. To reduce the likelihood of the latter, testing with multiple control series is recommended (Underwood 1994). Jeffries et al. (1989) showed that winter flounder abundance data for the period 1959-1985 had common signals regardless of where it was collected in RI waters. The stock management areas specified in ASMFC and NMFS stock assessments also imply commonality in gross abundance patterns. Rhode Island winter flounder are part of the southern New England and mid-Atlantic stock complex. These observations indicate that the use of multiple control series, sampled at different geographic scales, will be a powerful means to detect local impacts.

Ratio series were formed between the MRI standard trawl index and the control abundance series as:

$$Z_{tj} = M_t / I_{tj} \qquad (1)$$

where: Z= ratio of impact to control abundance
M= MRI standard trawl abundance
I= control index abundance

t= year
j= control series.

The resulting ratio series were log transformed and tested for time trends via linear regression:

$$\ln(Z_{tj}) = \ln(Z_0) + G_t + \varepsilon \qquad (2)$$

where: Z_0= ratio abundance at t=0
G= instantaneous rate of population change.
t= time
ε = combined process and measurement error term.

The logarithmic transformation in eq.2 stabilizes the variance in lognormally distributed survey data and is consistent with an underlying population dynamics model based on instantaneous rates of population change. For estimates of G<0, the population is declining while for G>0 it is increasing. In the special case of G=0, the population is stable without trend. The procedures above were applied to the MRI standard trawl index (impact) and the five candidate control series (NMFS trawl, URIGSO trawl, RIDFW trawl, commercial landings, MSS impingement). The procedures were then repeated substituting the BPS impingement index for the impact series. The analysis was restricted to the 1972-1985, pre-unit 4 period to evaluate conditions relative to permitting.

The regression test for time trend in eq.2 assumes that the error terms are independently and identically distributed with constant variance and mean of zero. Serial correlation occurs when the error terms are not independent but correlated with past error terms. Neter et al. (1983) summarize the problems encountered in regression analysis when serial correlation is present but not accounted for. The most important to this application is that standard errors of the slope parameter may be underestimated. This may result in type I error, that is concluding a significant trend when in fact none exists. Residuals from eq.2 were tested for serial correlation using the Durbin-Watson test (Neter et al. 1983). This test involves computing a ratio of the sum of squared residual differences to the sum of squared residuals (D):

$$D = \Sigma(\varepsilon_t - \varepsilon_{t-1})^2 / \Sigma\varepsilon_t^2 \,. \qquad (3)$$

When serial correlation is present, first differences in the residuals will be small and the numerator in eq.3 will be small relative to the denominator. Manley (2001) presents tabular values of D in relation to the number of independent variables and degrees of freedom in the regression model. Significant serial correlation is present when the computed D statistic is less than the lower 95% table value. No correlation is present when the computed D value exceeds the upper 95% limit. There is a range in the table for which the test is inconclusive.

<u>Plant Operational Data and Permit Conditions</u>- Since permit conditions for the facility are the issue at hand, managers need advice on the conditions that will likely result in a

recovery of the fishery resource to a balanced and indigenous state. RIDEM has maintained that pre-1985 operating conditions define possible limits for coolant flow and waste heat rejection as this period preceded the abrupt collapse of the winter flounder stock following unit 4 conversion. If these conditions are appropriate, the adjusted abundance series should have no trend from 1972-1985. That is, estimates of G in eq.2 should not be significantly different from zero. If that hypothesis is rejected and there is evidence that G<1.0, then the stock was declining in Mt. Hope Bay faster than in other areas. One would conclude that the pre-1985 conditions were not conservative enough and that the operation of units 1-3 had resulted in adverse impacts to winter flounder in Mt. Hope Bay.

Data on average circulating coolant flow and waste heat rejection were taken from the company 316(a) and (b) demonstration. These data were examined for trends over time and compared with the trajectories of winter flounder abundance. Possible permit conditions were identified as historical operational conditions when a stable stock of winter flounder existed.

Results-

Winter flounder abundance data used in this analysis is summarized in Table 1. Trawl survey results are plotted in Figure 1. Common features of the independently conducted surveys are low abundance in the mid-1970's followed by high abundance that persisted through about 1983. All surveys declined thereafter with the MRI survey showing a complete collapse to undetectable levels. The other surveys reached a historic low in 1993 but then showed some evidence of recovery. Of these, the NMFS survey shows the greatest increase since 1993 while the URIGSO survey shows the least. Commercial landings in statistical area 539 follow a similar pattern (Figure 2). Landings remain low but have been increasing since 1993. Impingement of winter flounder at BPS declined steadily from 1972 to 1988 with the exception of 1978, and has remained low since (Figure 3). Impingement at MSS featured a very large value in 1985 but otherwise was similar to trends in long-term trawl surveys. Recent levels are above that observed in the early 1990's. This series needs to be adjusted for coolant flow rates since it is not clear what impact station history and re-powering had on impingement rates.

MRI standard trawl abundance of winter flounder, as adjusted by control data using the procedures described in equations 1 and 2, is plotted in Figure 4. The large drop in abundance in the mid-1980's remains the dominant feature of the adjusted series. Clearly, a large reduction in winter flounder abundance occurred near BPS that did not occur in other areas. Of more interest to the permitting process are the slopes of the adjusted series during the period 1972 to 1985. All show evidence of decline. Detailed regression results are given in Table 2 and are summarized in Table 3. For the period 1972-1985, all slope estimates are negative. Estimates of G in eq.2 were negative and significantly (P<0.05) less than zero for the NMFS, URIGSO, and commercial landings control series. Estimates of G were negative for the RIDFW and MSS control series but the 95% confidence bound included zero. This is not surprising since the RIDFW series changed survey methodology in 1979 from fixed to random stations. Although efforts were made to account for the change, the extended series may lack continuity. The MSS series is not free of power plant impacts and is short relative to the other series.

BPS impingement, adjusted using the procedures described in eqs. 1 and 2, is plotted in Figure 5. Substitution of the impingement index at BPS for the MRI trawl survey confirms the trawl results for 1972-1985. Four of the five adjusted series have slope estimates (G) significantly less than zero at the $P<0.01$ level (Table 3). Only the MSS impingement (control) series did not reach conventional significance levels. Computed Durban-Watson statistics are included in Table 3. Of the 10 series tested, none indicated significant serial correlation in the residuals. Three tests were inclusive while seven resulted in non-significant conclusions. Accordingly, the regression model used in eq. 2 should yield reliable slope estimates and identify significant trends without risk of elevated type I error. Overall, the control-impact analysis provide strong evidence that winter flounder in Mt. Hope Bay near BPS declined at faster rates than in other areas during the period 1972-1985.

Trends in coolant water usage at BPS and waste heat rejected to Mt. Hope Bay are shown in Figure 6. Coolant flow rose from 50 billion gallons per year in 1963 to 300 billion in 1973 as generating units were brought on line. Cooling water usage fluctuated between 250 billion and 300 billion gallons per year from 1970 to 1984. A sharp increase began in 1985 and coolant flow exceeded 350 billion from 1986 to 1996. Recent levels have been between 300 billion and 350 billion. Waste heat to Mt. Hope Bay rose from 4 trillion in 1963 to 30 trillion in 1973 with increasing power generation. Heat load to the Bay fluctuated between 20 trillion and 30 trillion BTUs from 1970 to 1981. In 1982, a steady increase began which accelerated in 1986 and peaked at around 50 trillion BTUs in 1988-1990. Heat load declined somewhat in 1991 and has been steady at around 40 trillion BTU. Although plant coolant flow and waste heat rejection are highly correlated ($r=0.95$), some deviations are noteworthy. The operational data are plotted as a BTU-Flow phase diagram in Figure 7. There is a clear transition in plant operations in the mid-1980's when coolant flow increased before waste heat. The observational data may be broadly grouped into four periods:

Period 1- 1963-1969, initial start up and addition of generating units

Period 2- 1970-1981, operation of units 1-3 with unit 4 in closed cycle beginning in 1974.

Period 3- 1982-1986, conversion of unit 4 from closed cycle cooling, to piggyback mode and then to open cycle cooling.

Period 4- 1987-1996, high power operation of all units with maximum coolant flow and waste heat rejection.

Period 5- 1997-2000, MOA II operation with reduced output.

Referring again to Figure 4, it is clear that period 3 was a watershed event for the winter flounder stock in Mt. Hope Bay. All of the adjusted abundance series were in a decline that accelerated in 1985 or 1986. Viewed in the context of plant history, the operation of units 1-3 was sufficient to cause a reduction in Mt. Hope Bay winter flounder abundance relative to other areas. The large increase in flow and waste heat associated with unit 4 conversion accelerated the decline. That winter flounder have not shown signs of recovery in either the trawl or impingement data indicates that flow and BTU limits under MOA II are above that needed to rebuild the population. Since the population was clearly in decline relative to other areas from 1972 to 1985, average operational conditions then were also excessive for the population. Mean flow and waste heat rejection at BPS from 1972 to 1985 were 266.0 (SE=5.7) billion gallons and 28.9 (SE=0.9) trillion BTU respectively. Since the average plant operational conditions during 1972-1985 contributed to a winter flounder decline, new permit conditions should be significantly below this average. Resource monitoring did not commence until 1972, well after commercial operation began, so it is not clear from abundance and plant operational data how low flow and BTU need to be reduced to enable recovery.

Discussion-

An important permitting issue for the RIDEM, EPA, and MADEP is a set of conditions that will allow Mt. Hope Bay fish stocks to return to a balanced and indigenous state and to meet state water quality standards. It should be clear from the above analysis that winter flounder abundance in Mt. Hope Bay is anomalously low compared to other areas in and outside of Narragansett Bay. A control-impact analysis was used to confirm the large drop in abundance that occurred in 1985-1986. Multiple control abundance series measured in and outside of Narragansett Bay were used to characterize regional abundance patterns and to reduce the likelihood of Type I error in time trend analysis. Abundance of winter flounder in Mt. Hope Bay in 2000 is still well below that observed in other areas. With regard to permit conditions, there is statistical evidence of a decline in the Mt. Hope Bay winter flounder stock from 1972-1985 relative to other areas. These results are interpreted to mean that the operation of units 1-3 during 1972-1985 was sufficient to induce a decline in the winter flounder stock. Conversion of unit 4 to open cycle cooling accelerated this decline and led to the complete collapse of the stock. The conversion was associated with a large increase in coolant flow, followed by a large increase in waste heat rejection.

Mean flow and waste heat rejection at BPS from 1972 to 1985 were 266.0 (SE=5.7) billion gallons and 28.9 (SE=0.9) trillion BTU respectively. As noted above, these operational conditions were associated with a significant decline in the abundance of winter flounder in Mt. Hope Bay that was not observed in other areas. Accordingly, new permit conditions should specify flow and heat rejection levels below the 1972-1985 mean levels. It is emphasized that the lack of monitoring data prior to 1972 precludes direct estimation of overall flow and heat limits conducive to a healthy population of winter flounder. Additional guidance from state water quality standards, life history studies, and sustainable removal rates is needed. Also, there may be seasonal, life history considerations that need be addressed within overall flow and heat limits.

Finally, there is no assurance that conditions that once supported a healthy population, will allow for recovery of a collapsed population. Indeed, recovery may be difficult to achieve without large reductions in plant induced and fishing mortality if long-term environmental trends (increasing water temperature) and type III predation are present (Collie and Spencer 1994). The former is known to be occurring and the latter is suspected in the form of invertebrate predation on larvae and YOY flounder. Long-term trends in environmental conditions and depensatory predation may interact with anthropogenic sources of mortality to drive a population into what is known as a "predator pit" (Hilborn and Walters 1992). They note that under these circumstances, a population may not recover after fishing pressure is reduced. This should not be interpreted to mean that nothing can be done but that, in the face of uncertainty over stock dynamics, permit conditions for power plants and fishery regulations should be overly protective of the resource in question.

Literature Cited

Anthony, V.C. 1990. The New England ground fish fishery after 10 years under the Magnuson Fishery Conservation and Management Act. N. American J. Fish. Mgt. 10: 175-184.

Clark, S.H. 1979. Application of bottom trawl survey data to fish stock assessment. Fisheries 4: 9-15.

Collie, J.S. and P.D. Spencer. 1994. Modeling predator-prey dynamics in a fluctuating environment. Can. J. Fish. Aquat. Sci. 51: 2665-2672.

Gibson, M.R. 1987. Preliminary assessment of winter flounder (*pseudopleuronectes americanus*) stocks in Rhode Island waters. RI Division of Fish and Wildlife. Res. Ref. Doc. 87/7.

Gibson, M.R. 1994. Population dynamics of winter flounder in Mt. Hope Bay in relations to operations at the Brayton Point Electric Plant. RI Division Fish and Wildlife. Report to the Brayton Point Technical Advisory Committee, May 1992. Revised December 1993.

Gibson, M.R. 1996. Comparison of trends in the finfish assemblage of Mt. Hope Bay and Narragansett Bay in relation to operations at the New England Power Brayton Point Station. RI Division Fish and Wildlife Research Reference Document 95/1. Revised August 1996.

Gibson, M.R. 2000. Recent trends in abundance, recruitment, and fishing mortality for winter flounder in Narragansett Bay and Rhode Island coastal waters. RI Division of Fish and Wildlife. Report to the RI Marine Fisheries Council.

Grosslein, M.D. 1969. Groundfish survey program of the BCF Woods Hole Comm. Fish. Rev. 31: 22-35.

Harley, S.J., R.A. Myers, and A. Dunn. 2001. Is catch-per-unit-effort proportional to abundance? Can. J. Fish. Aquat. Sci. 58: 1760-1772.

Hilborn, R. and C.J. Walters. 1992. Quantitative Fish Stock Assessment: Choice, Dynamics, and Uncertainty. Chapman and Hall, New York. 570 p.

Jeffries, H.P., A. Keller, and S. Hale. 1989. Predicting winter flounder (Pseudopleuronectes americanus) catches by time series analysis. Can. J. Fish. Aquat. Sci. 46: 650-659.

Lynch, T.R. 1999. Assessment of recreationally important finfish stocks in Rhode Island coastal waters, 1979-1998. RI Division Fish and Wildlife. Annual Progress Report. Job F-61-R-1.

Madenjian, C.P., J. Jude, and F. J. Tesar. 1986. Intervention analysis of power plant impact on fish populations. Can. J. Fish. Aquat. Sci. 43: 819-829.

Manley, B.F.J. 2001. Statistics for Environmental Science and Management. Chapman and Hall/CRC. New York 326 p.

Neter, J., W. Wasserman, and M.H. Kutner. 1983. Applied linear regression models. Richard B. Irwin, Inc. Homewood, IL. 547 p.

Perlmutter, A. 1947. The blackback flounder and its fishery in New England and New York. Bull. Bingham Oceanogr. Collect., Yale Univ. 11(2). 92 pp.

Underwood, A.J. 1994. On beyond BACI: sampling designs that might reliably detect environmental disturbances. Ecological Applications 4: 3-15.

USGen New England, Inc. (USGEN). 2001. Variance request application and partial demonstration under the clean water act, section 316(a) and (b) in support of renewal of NPDES Permit No. MA 000 3654 for USGEN New England, Inc.'s Brayton Point Station. May 24, 2001.

USGEN/MRI. 1999. Annual Hydrobiological Report.

Van Winkle, W., D.S. Vaughan, L.W. Barnthouse, and B.L. Kirk. 1981. An analysis of the ability to detect reductions in year-class strength of the Hudson River white perch (*Morone americana*) population. Can. J. Fish. Aquat. Sci. 38: 627-632.

Appendix- Proof that the ratio of two independent series, both representative of the same process, is a series without trend.

For this exercise, I assume that a simple exponential growth model governs the population dynamics of a stock:

$$N_t = N_0 \exp(Gt) \exp(❀_p) \qquad (1)$$

where:

N= number in population
N_0= initial number
t= time
G= instantaneous rate of change.
$❀_p$= process error.

The rate parameter G has additive components due to births, natural deaths, and losses from fishing and other sources. In fisheries terminology, these are equivalent to recruitment (R), natural mortality rate (M1), fishing mortality rate (F), and anthropogenic mortality rate (M2). For values of G greater than 1.0, the population increases. If G is exactly 1.0, the population is stable around a constant value. For G less than 1.0, the population is declining. The error term allows for deviations from the process due to variability in growth, recruitment, natural mortality, etc. Error in eq. 1 is multiplicative in nature, i.e. they are normally distributed in the log scale with zero mean and constant variance.

Since actual population sizes are unknown, an observation model is needed which relates true abundance to the relative abundance in a survey:

$$N_t = I_t/q \exp(❀_m) \qquad (2)$$

Where:

N= population size
I= survey relative abundance
Q= catchability coefficient
$❀_m$= measurement error
t= time.

The multiplicative error term allows for deviations in the measured index from its true value. As above, errors are normally distributed with zero mean and constant variance in the log scale. Substituting eq.2 into eq.1 and combining error terms yields an estimation model amenable to analysis when relative abundance data is available, for example in the form of a trawl survey:

$$I_t = I_0 \exp(Gt) \exp(❀_p + ❀_m) \qquad (3)$$

The usual form of analysis is to make a logarithmic transformation of eq.3 and use least squares regression to estimate parameters:

$$\ln(I_t)= \ln(I_0)+Gt+(❀_p+❀_m) \qquad (4)$$

The rate of change in the population (G) is estimated as the slope of the regression. Note that in eq.4, it is not possible to separate the process and measurement errors. When there are two abundance indices, both representative of the stock, a ratio series of the corresponding elements should be stationary with constant mean and variance. This can be shown as follows.

For two series designated by subscript as 1 and 2, define a ratio series as:

$$Z_t= I_{1t}/I_{2t} \qquad (5)$$

Substitution of eq.3 into eq.5 and carrying through the subscripts yields:

$$Z_t= [I_{10} \exp(G_1t) \exp(❀_{1p}+❀_{1m})]/ [I_{20} \exp(G_2t) \exp(❀_{2p}+❀_{2m})]. \qquad (6)$$

Because the surveys are representative of the stock in question, $G_1=G_2$ and $❀_{1p}= ❀_{2p.}$ Expanding the errors, canceling common terms, and simplifying yields:

$$Z_t= I_{10}/I_{20} \exp(❀_{1m}-❀_{2m}). \qquad (7)$$

That is, the ratio series consists of a constant modified by a combination of the measurement errors for the respective relative abundance series. The series has no trend as $\exp(G_1t-G_2t)=1$. The linear combination of normally distributed measurement errors is itself normally distributed with constant and variance. The time pattern of the ratio series in eq.7 is therefore lognormal variation about a constant. In the case that $G_1γG_2$, then the terms do not cancel and:

$$Z_t= I_{10}/I_{20} \exp((G_1-G_2)t)\exp(❀_{1m}-❀_{2m}). \qquad (8)$$

The ratio series has a trend with the rate of change given by the difference in the slopes of the original two series. In the context of impact assessment, this would indicate a difference between the control and impact series.

Table 1- Winter Flounder Abundance Indices for the Rhode Island Area

Year	NMFS BIS Kgs/tow	URIGSO No./tow	MRI No./tow	RIDFW No./tow	539 Comm Landings MT	MRI Brayton Impingement	Manchester St Impingement
1959		14.88			809.3		
1960		13.94			864.9		
1961		16.90			728.0		
1962		18.30			728.4		
1963		16.14			1045.5		
1964		14.93			1591.5		
1965		22.65			1117.8		
1966		28.88			1617.0		
1967		46.59			1320.3		
1968	0.73	50.85			1274.7		
1969	3.41	40.96		46.27	998.9		
1970	1.33	27.77		49.01	860.0		
1971	0.76	18.04		10.73	671.2		
1972	0.66	15.36	43.65	18.31	438.5	17.11	
1973	2.01	15.54	60.37	32.13	523.1	14.57	
1974	1.04	13.67	36.24	33.57	390.7	20.16	
1975	0.35	9.48	18.89	28.13	360.8	3.72	2381
1976	0.81	7.84	10.60	14.27	379.5	4.03	1148
1977	1.19	10.87	16.46	31.96	483.5	12.40	1503
1978	1.76	28.63	48.56	26.56	660.4	17.83	3017
1979	1.07	51.19	78.02	97.97	820.8	4.34	15101
1980	3.55	42.51	15.75	39.62	1276.3	6.67	8149.5
1981	4.76	31.74	19.35	56.59	1101.6	4.19	3273
1982	1.92	24.59	49.97	24.99	1324.0	1.71	11207
1983	2.47	41.40	43.01	38.13	1231.1	3.26	4212
1984	2.07	19.69	17.93	30.33	1292.5	5.89	1572
1985	1.98	8.76	14.97	28.20	1161.6	7.91	25340
1986	0.77	6.47	5.82	36.04	853.0	4.65	748
1987	0.57	16.44	2.09	38.56	621.6	9.46	7106
1988	0.73	13.80	0.73	22.54	505.2	1.86	5516
1989	0.58	9.11	0.37	14.02	444.1	4.19	2365
1990	0.47	5.10	0.97	14.58	402.0	1.55	10823
1991	0.69	4.25	0.57	21.86	660.8	2.48	2422
1992	0.44	3.05	0.49	7.50	358.7	0.93	1660
1993	0.22	4.96	0.99	4.79	246.8	4.34	1935
1994	0.33	3.11	0.44	6.23	380.0	2.48	912
1995	0.59	14.41	0.91	20.69	413.5	2.64	4295
1996	0.43	10.30	0.61	15.74	342.1	1.71	15360
1997	0.40	10.76	0.90	8.39	400.8	1.63	13398
1998	0.85	6.74	0.53	10.62	498.0	0.47	5902
1999	1.25	3.31	0.26	8.13	432.0	1.71	9716
2000	1.63	3.56	0.11	9.45	558.3	0.45	3948
Mean	1.27	18.27	16.88	26.43	766.40	5.67	6269.60
STD	1.05	13.54	21.83	18.83	379.39	5.53	5951.64
CV	0.83	0.74	1.29	0.71	0.50	0.98	0.95

Table 2- Regression Details for Tests for Time Trends in
MRI Winter Flounder Abundance Data

SUMMARY OUTPUT for NMFS adjusted log trend 72-85

Regression Statistics	
Multiple R	0.602155
R Square	0.362591
Adjusted R Square	0.309473
Standard Error	0.780515
Observations	14

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4.158547	4.15854 7	6.82620 7	0.022688
Residual	12	7.310438	0.60920 3		
Total	13	11.46899			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	268.1303	102.3829	2.61889 8	0.02243	45.05719	491.2034
X Variable 1	-0.1352	0.051748	-2.6127	0.02268 8	-0.24795	-0.02245

SUMMARY OUTPUT for URIGSO adjusted log trend 72-85

Regression Statistics	
Multiple R	0.580694
R Square	0.337206
Adjusted R Square	0.281973
Standard Error	0.525464
Observations	14

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.685712	1.68571 2	6.10516 1	0.029447
Residual	12	3.313351	0.27611 3		
Total	13	4.999062			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	170.6969	68.92699	2.47648 8	0.02914 5	20.51787	320.8759
X Variable 1	-0.08608	0.034838	2.47086	-0.02944 7	-0.16199	-0.01017

SUMMARY OUTPUT for Landings adjusted trend 72-85

Regression Statistics	
Multiple R	0.75182
R Square	0.565234
Adjusted R Square	0.529003
Standard Error	0.554505
Observations	14

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4.796951	4.79695 1	15.6010 5	0.001928
Residual	12	3.689714	0.30747 6		
Total	13	8.486665			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	287.9632	72.73643	3.95899 6	0.00189 7	129.4842	446.4423
X Variable 1	-0.14521	0.036763	3.94982	-0.00192 8	-0.22531	-0.06511

SUMMARY OUTPUT for RIDFW adjusted 72-85 trend

Regression Statistics	
Multiple R	0.431002
R Square	0.185762
Adjusted R Square	0.117909
Standard Error	0.595033
Observations	14

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.969326	0.96932 6	2.73771 4	0.123904
Residual	12	4.248769	0.35406 4		
Total	13	5.218095			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	129.0209	78.05256	1.653	0.12423 4	-41.041	299.0828
X Variable 1	-0.06527	0.03945	-1.6546	0.12390 4	-0.15123	0.02068

SUMMARY OUTPUT for NMFS adjusted impingement

Regression Statistics	
Multiple R	0.769635
R Square	0.592338
Adjusted R Square	0.558366
Standard Error	0.721328
Observations	14

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	9.072269	9.072269	17.43614	0.001286
Residual	12	6.243768	0.520314		
Total	13	15.31604			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	394.3169	94.61914	4.167412	0.001305	188.1595	600.4743
X Variable 1	-0.1997	0.047824	-4.17566	0.001286	-0.30389	-0.0955

SUMMARY OUTPUT for URIGSO adjusted impingement

Regression Statistics	
Multiple R	0.574571
R Square	0.330132
Adjusted R Square	0.27431
Standard Error	0.933899
Observations	14

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	5.15798	5.15798	5.913986	0.031624

	df	SS	MS	F	Significance F
Residual	12	10.466	0.87216 6		
Total	13	15.62398			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	296.8835	122.5028	2.42348 4	0.03211 2	29.97288	563.7941
X Variable 1	-0.15057	0.061917	2.43187	-0.03162 4	-0.28548	-0.01567

SUMMARY OUTPUT for Landings adjusted impingement

Regression Statistics	
Multiple R	0.792822
R Square	0.628566
Adjusted R Square	0.597613
Standard Error	0.701889
Observations	14

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	10.00434	10.0043 4	20.3072 5	0.000719
Residual	12	5.911784	0.49264 9		
Total	13	15.91612			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	414.843	92.06931	4.50576 8	0.00071 9	214.2412	615.4448
X Variable 1	-0.2097	0.046535	4.50636	-0.00071 9	-0.31109	-0.10831

SUMMARY OUTPUT for RIDFW adjusted impingement

Regression Statistics	
Multiple R	0.57322
R Square	0.328581

Adjusted R Square	0.272629
Standard Error	0.807692
Observations	14

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3.831073	3.831073	5.872585	0.032121
Residual	12	7.828389	0.652366		
Total	13	11.65946			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	255.2075	105.9478	2.408805	0.032985	24.36717	486.0479
X Variable 1	-0.12977	0.053549	-2.42334	0.032121	-0.24644	-0.01309

SUMMARY OUTPUT for Manchester St adjusted 72-85 trawl

Regression Statistics	
Multiple R	0.468708
R Square	0.219687
Adjusted R Square	0.132985
Standard Error	0.885568
Observations	11

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.987108	1.987108	2.53383	0.145893
Residual	9	7.058079	0.784231		
Total	10	9.045187			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	267.8731	167.1827	1.60227	0.14355	-110.321	646.067

X Variable 1	-0.1344	0.084436	7 -1.5918	8 0.14589 3	-0.32541	0.056602

SUMMARY OUTPUT for Manchester St. adjusted impingement

Regression Statistics	
Multiple R	0.475936
R Square	0.226515
Adjusted R Square	0.140572
Standard Error	1.216323
Observations	11

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3.89929	3.89929	2.63564 9	0.138937
Residual	9	13.31498	1.47944 2		
Total	10	17.21427			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	372.3136	229.6246	1.62140 1	0.13938 2	-147.134	891.7609
X Variable 1	-0.18828	0.115972	1.62347	-0.13893 7	-0.45062	0.07407

Table 3- Estimates of Instantaneous Rate of Decline in Winter Flounder Abundance for Period 1972-1985 Based on the MRI Standard Trawl and Brayton Impingement Series as Adjusted by Several Control Series.

Impact Series-MRI Standard Trawl

Control Series	Slope	SE	F Stat	Prob	D-W Stat
NMFS Trawl	-0.135	0.052	6.826	0.023	2.168
URIGSO	-0.086	0.035	6.105	0.029	1.534

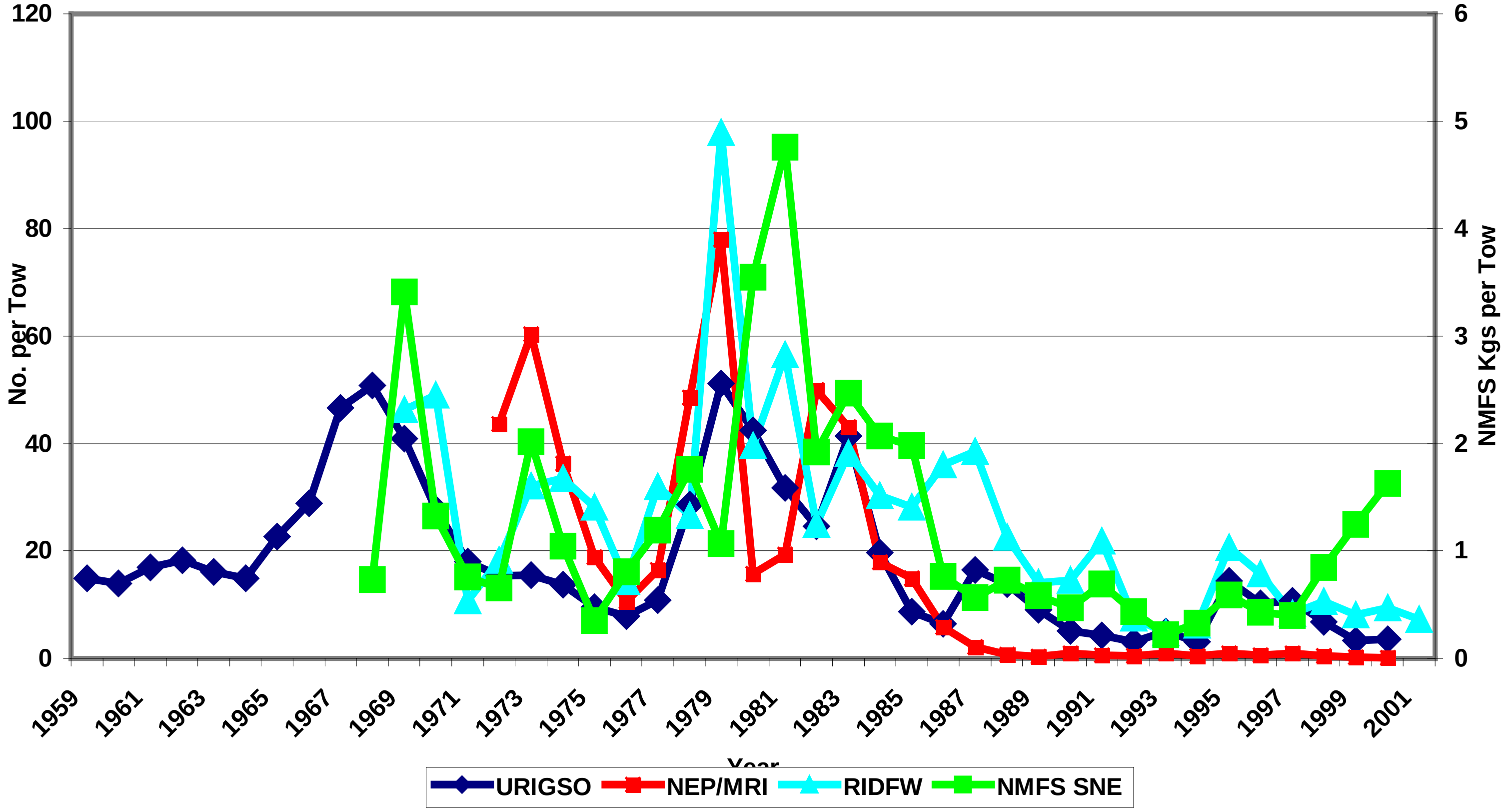
Comm Landings	-0.145	0.037	15.601	0.002	1.873
RIDFW Trawl	-0.065	0.040	2.738	0.124	1.711
Manchester St	-0.134	0.084	2.534	0.146	1.073

Impact Series- Brayton Impingement

Control Series	Slope	SE	F Stat	Prob	D-W Stat
NMFS Trawl	-0.200	0.048	17.436	0.001	1.061
URIGSO	-0.151	0.062	5.914	0.032	1.456
Comm Landings	-0.210	0.047	20.307	0.001	1.850
RIDFW Trawl	-0.130	0.054	5.873	0.032	1.032
Manchester St	-0.188	0.116	2.636	0.139	2.066

/1
A ? indicates that the computed value of D falls within inconclusive range of the D-W test

Fig.1- Winter Flounder Abundance in the URIGSO, MRI, RIDFW and NMFS Trawl Surveys



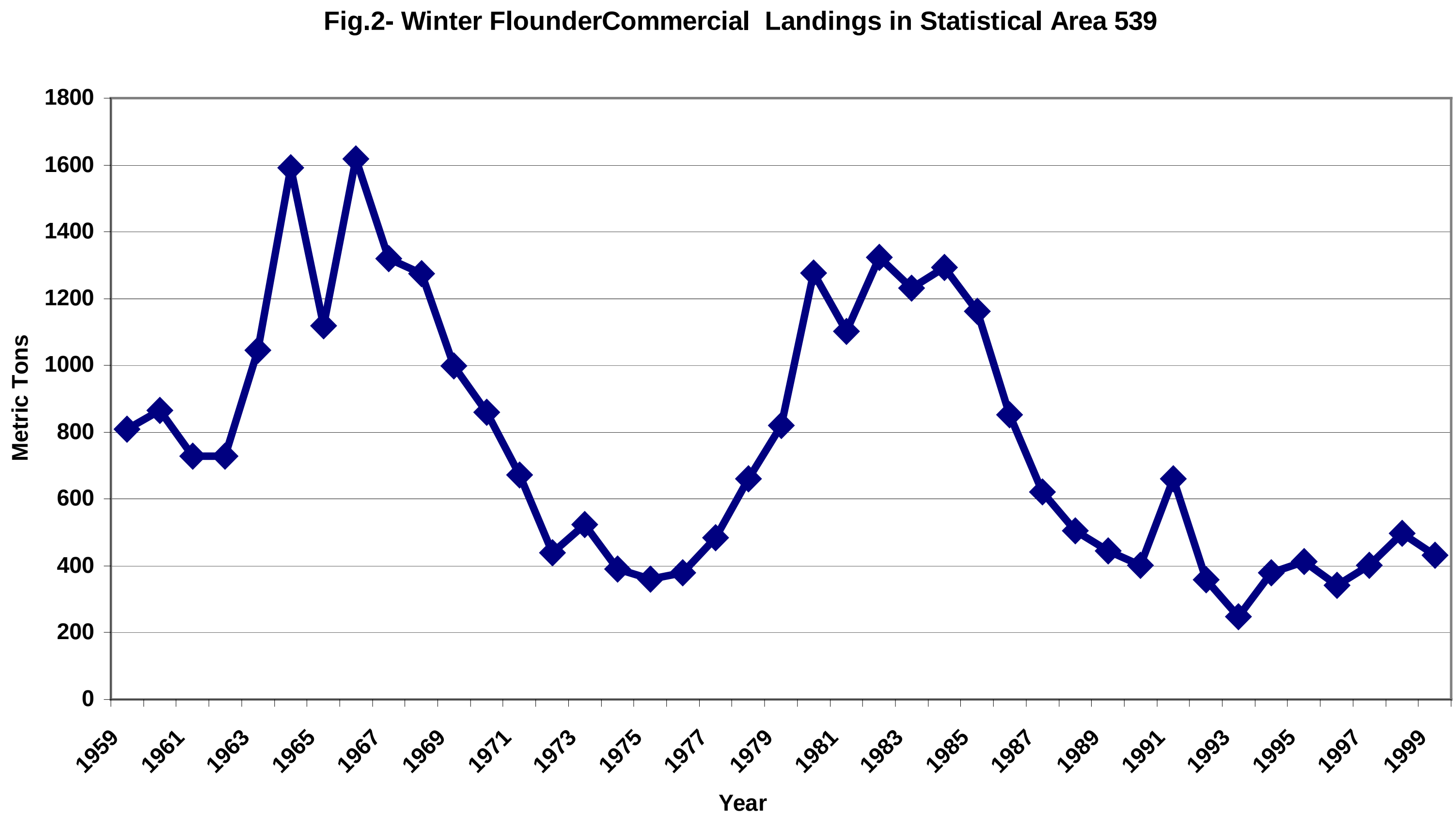


Fig.2- Winter FlounderCommercial Landings in Statistical Area 539
Metric Tons
1800
1600
1400
1200
1000
800
600
400
200
0
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
Year

Fig.3- Impingement of Winter Flounder at Power Stations in Narragansett Bay

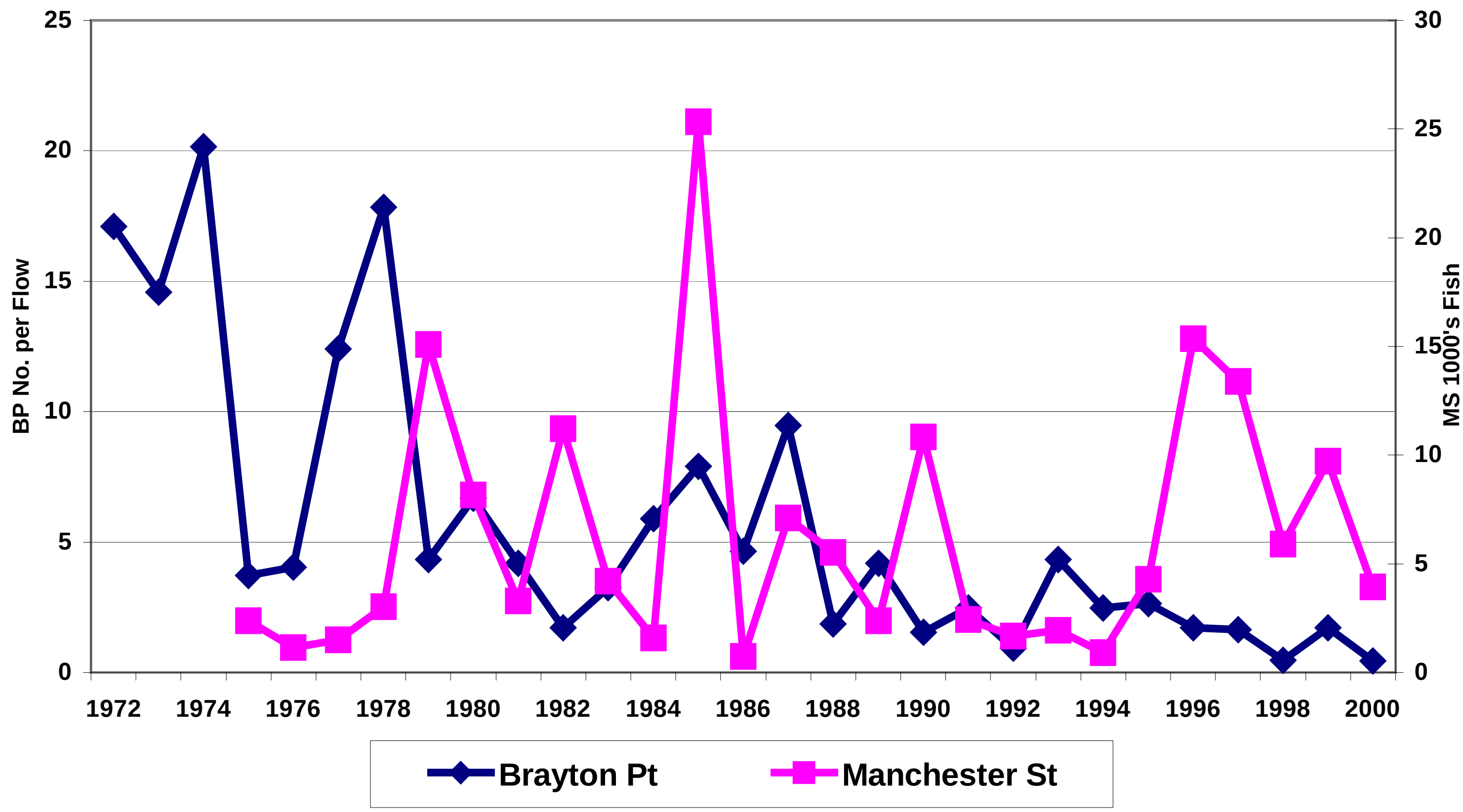


Fig.4- Winter Flounder Abundance in the MRI Trawl Survey Adjusted for Regional Conditions Using Other Long Term Abundance Data

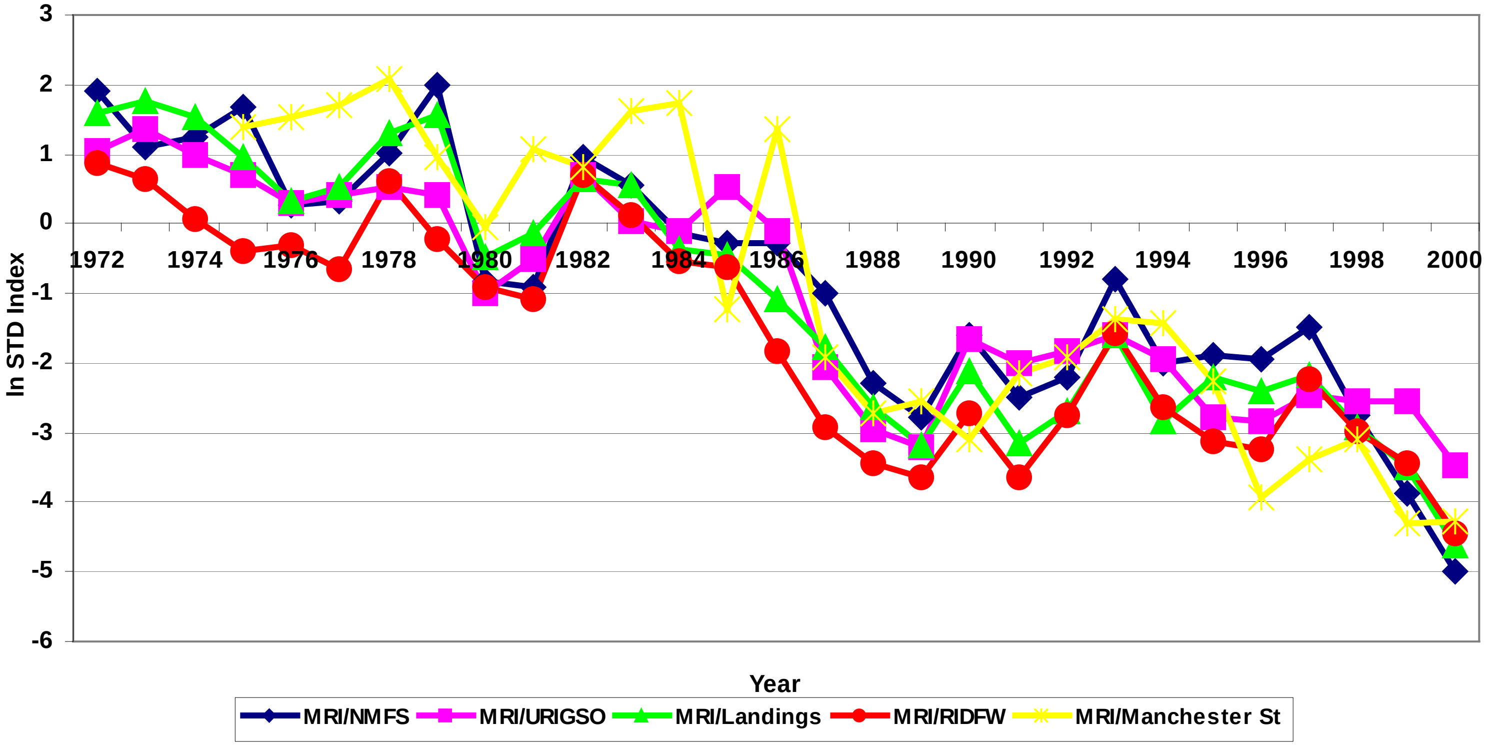
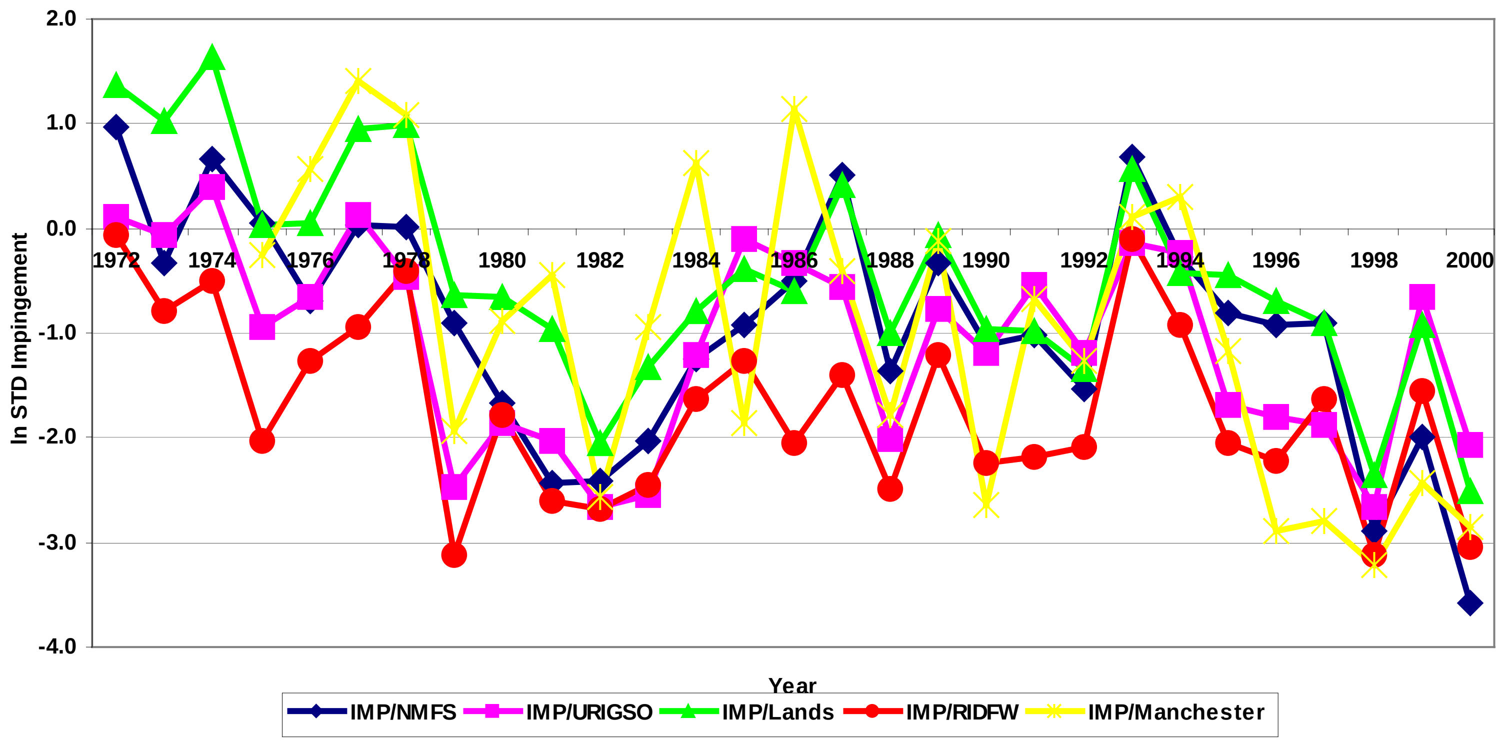


Fig.5- Winter Flounder Abundance from Brayton Point Impingement Adjusted for Regional Conditions Using other Long Term Abundance Data



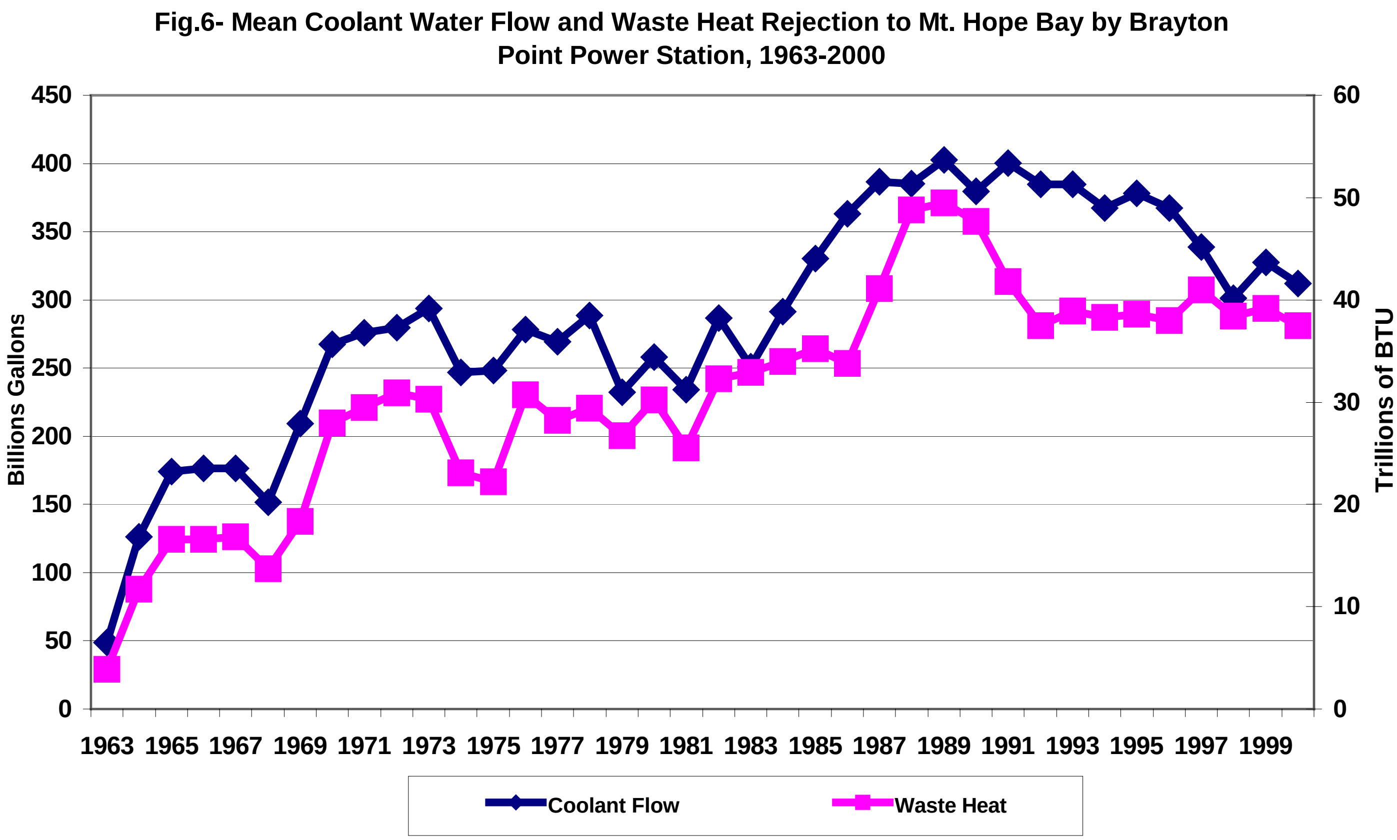


Fig.6- Mean Coolant Water Flow and Waste Heat Rejection to Mt. Hope Bay by Brayton Point Power Station, 1963-2000
Billions Gallons
Trillions of BTU
0
50
100
150
200
250
300
350
400
450
0
10
20
30
40
50
60
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
Coolant Flow
Waste Heat

Fig.7- Waste Heat Rejected to Mt. Hope Bay vs. Amount of Coolant Water Used by Brayton Station, 1963-2000